European Climate Research Alliance Collaborative Program Polar Research Paper 2023

Climate research needs and challenges in the polar regions: ECRA's perspective

Climate change is happening at an alarming rate in the polar regions, with temperature increases in parts of the Arctic and Antarctic up to six times that of the global average and dramatic recent declines in Antarctic sea ice. The polar environment changes rapidly as the temperature crosses the freezing point, and melting glaciers, sea ice, and permafrost have numerous local and global consequences. Although geographically isolated from most human populations, changes in the Antarctic and the Arctic (hereinafter polar regions) have global implications as part of the interconnected global climate system. As the climate system moves beyond the historical range of conditions, a reliable representation of physical processes (such as cloud formation) in climate models is as important as ever. For example, the potential to be caught out by surprising extreme weather and climate events is increasing. This, combined with continued development in observational capabilities, is crucial to provide information to make well-informed policy decisions.

ECRA aims to bridge the gap between the scientific community and decision-makers, identifying emerging fields in climate science, consolidating the latest findings, shaping research collaborations, and informing on the latest climate research. To this end, we have identified three essential topics in polar climate science to respond to the challenges of human-induced climate change.

Observations and monitoring

Observations are crucial to building our understanding of the physical system. At the same time, continuous monitoring is required for up-to-date information on the state of the climate system and to support both short-term forecasting and seasonal to decadal prediction efforts. In the polar regions, it is vitally important to continue the Copernicus program and to continue innovating in the use of climate observations from in-situ and remote satellite-based monitoring of the earth to help improve climate models and the projections made from them. The polar regions are areas of intense exchanges at the ocean-atmosphere interface, and enhanced observations and monitoring of critical locations and processes of atmosphere-ocean-ice interactions are needed.

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Process understanding and linking scales

The climate system is complex, and a cornerstone in understanding the whole is identifying and understanding a myriad of underlying physical processes - such as cloud formation or the exchange of heat between the ocean and atmosphere. Process understanding should form the bedrock from which we build models of the climate system, as this will not change even though the climate will. Linking small-scale processes, such as droplet formation, with large-scale processes, such as the cloud cover of the polar regions, is essential for a complete picture of the climate system. Such understanding is achieved by combining theoretical knowledge and modelling capabilities with observational evidence. In the polar regions, this approach is recently exemplified by the MOSAiC expedition, where large amounts of observational data have been gathered to deepen our understanding of multiple small-scale processes over the high Arctic. To ensure that models accurately simulate the rapidly changing system, it will be vital to follow up on this with similar observational campaigns whilst also including similar levels of investment for in-depth data analysis to improve our understanding of the observed processes.

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Climate variability and change

Climate variability (annual-to-decadal fluctuations) and change (underlying multi-decadal trends) remain the overarching themes for climate research. Understanding climate variability and human-induced changes is critical to any adaptation and mitigation strategy. Climate change is amplified in the polar regions, which can cause knock-on effects that are sometimes poorly understood. Furthermore, research on the attribution of causes of extreme weather events offers the potential for a deeper understanding of human influence on these events. We must carefully observe, study, and understand the polar climate system to increase confidence in our analysis of climate variability and projected changes.

ECRA's research strategy for the Polar Collaborative Program (CP)

The complexity and challenges of observing and modelling the polar regions mean significant gaps in our scientific understanding remain. Improved knowledge and new insights to address these gaps are required to quantify better the impacts of polar change on lower latitudes. To help address these gaps, three areas of particular focus are recommended for European collaborative research efforts:

1. Small scales - big impacts: what are the small-scale processes that communicate the effects of climate change to large-scale responses in the climate system?
2. What will be the patterns of polar climate change, and what are their driving mechanisms and impacts?
3. What are the drivers of recent extreme weather and climate events, how did extreme events change due to anthropogenic factors, and how will extremes change under future emissions scenarios?

Question 1, about how small-scall processes impact the large scale, is crucial for the polar regions, as many of the small-scale processes active there are insufficiently understood and represented in large-scale models. This makes assessing these processes' regional or global impact difficult and casts doubt on whether their model representation is valid beyond the current climate. Such a situation is not viable in a changing climate, where the nature, role, and importance of many small-scale processes are likely to change. In ECRA, we wish to focus on a selected set of research challenges, including the heat and moisture transfer through openings in the sea ice, how this impacts the ocean and atmosphere boundary layers, and how winds depend on the momentum transfer between the surface, the atmospheric boundary layer, and the free atmosphere above. Beyond physical parameterisations, we are interested in utilising physics-informed artificial intelligence tools.

Question 2 focuses on patterns of polar climate change. Research into understanding the more rapid warming over the polar caps compared to the rest of the planet (polar amplification) provides valuable broad insight. However, studies of average polar cap change can mask more regional trends that are more directly linked to specific causes and impacts. To facilitate this understanding, we aim to focus on how the polar change in the different areas is impacted by various processes or parts of the climate system, including sea ice, precipitation and snow, clouds, and aerosols, as well as linkages to lower latitudes through atmospheric and oceanic pathways.

Question 3 addresses the extreme events in the polar regions, their drivers, their attribution, and expected changes. Understanding extreme events requires understanding the climate system's internal variability, regional scale dynamics, and the processes associated with specific events. This introduces diverse challenges, as we need the involvement of running a low-resolution climate model many times to enhance our understanding of internal variability. At the same time, detailed multi-model, higher-resolution modelling is necessary to understand the regional scale dynamics and processes. Observations are also challenging due to the rare and unpredictable nature of extreme events. In ECRA, we will focus on gathering sufficient observations of extreme events, determining the leading causes of extreme events, testing the extent to which they are realistically simulated in climate models, pursuing multi-method attribution of extreme events, and improving the representation of processes required for the reliable representation of extreme events in models at different resolutions.